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INTEGRATED COST-SCHEDULE RISK ANALYSIS

ESTIMATE ACCURACY: DEALING WITH REALITY

QUANTIFYING ESTIMATE ACCURACY AND PRECISION FOR THE PROCESS INDUSTRIES: A REVIEW OF INDUSTRY DATA

COMMON ERRORS IN DEALING WITH PROJECT RISK

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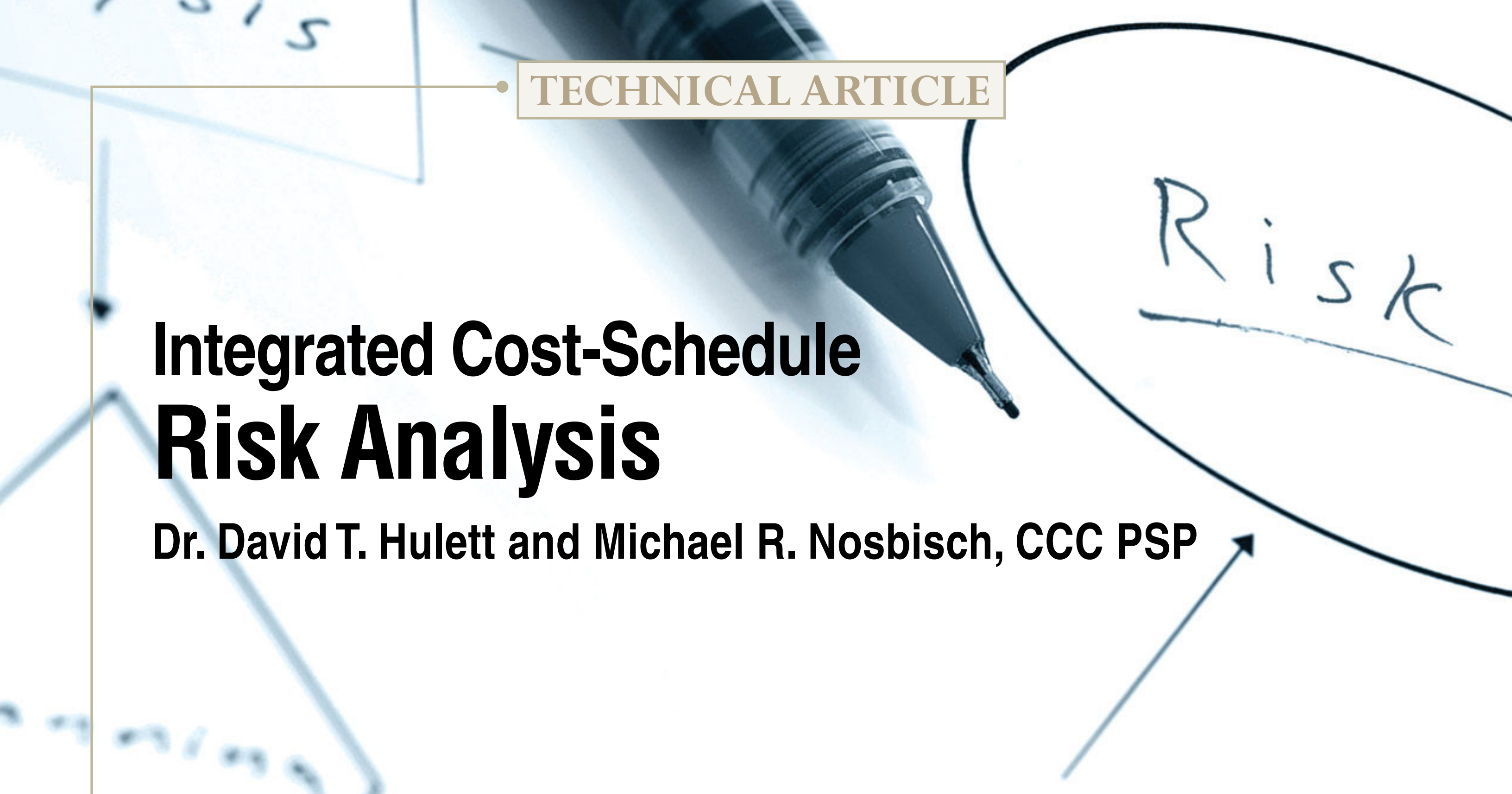
TECHNICAL ARTICLE



Integrated Cost-Schedule Risk Analysis

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Abstract: This article is based on AACE International Recommended Practice 57R-09 that defines the integrated analysis of schedule and cost risk to estimate the appropriate level of cost and schedule contingency reserve on projects. The main contribution of this RP is to include the impact of schedule risk on cost risk and the need to hold cost contingency reserves. Additional benefits include the application of the risk drivers method of using risks to drive the Monte Carlo simulation of a resource-loaded CPM schedule. By using the risks, one can prioritize the risks to cost, some of which are commonly thought of as risks to schedule, so that risk mitigation may be conducted in an effective way. The methods presented in the RP are based on integrating the cost estimate with the project schedule by resource-loading and costing the schedule's activities. Using Monte Carlo techniques one can simulate both time and cost simultaneously, permitting calculation of the impacts of schedule risk on cost risk. This article was presented as RISK.1043 at the 2012 AACE International Annual Meeting in San Antonio, Texas. It was ranked as the number three paper out of 99 presentations given and rated at the Annual Meeting.

Key Words: Contingency, cost, estimates, mitigation, Monte Carlo, projects, risk, and schedule

This article describes an improvement in cost risk analysis over the traditional methods that address cost risk without explicit reference, or any reference at all to the project schedule and its risk. It is now known how to represent the role that schedule risk has in driving project cost, because the longer some resources, such as engineering or construction work, the more they cost. One can also identify the risks that cause overall cost (and schedule) objectives to be placed in jeopardy, so one can use the results to conduct a risk mitigation exercise to improve the project's prospects for success.

The platform of this cost risk analysis is a resource-loaded project schedule. One may use a summary schedule or a detailed project schedule. The budget is assigned to the activities using summary resources to insert the entire budget into the schedule at the activity level.

Monte Carlo simulation is the most commonly used approach to analyzing the impact of multiple risks on the overall project schedule or cost risk. Simulating a resource-loaded project schedule derives consistent results for project schedule and cost in each iteration.

Context

Corporate culture is important. The organization should be "risk-aware." Management sets this tone, must want to know the truth about the risks to the project, and must view the risk analysis as an important input to project success. Management must be seen to use the risk analysis results as they make key project decisions. Without this condition the analysis will fail, no matter how much sophisticated software and training the staff has had, because the risk data will not be high-quality.

Traditionally, schedule risk has not been a major factor in assessments of cost risk. More recently cost risk analyses have included attempts to represent uncertainty in time, but usually these analyses occurred outside of the framework of the project schedule.

Only recently have the tools been available to include a full analysis of the impact of schedule uncertainty on the uncertainty in cost. The Monte Carlo tools first calculated labor cost proportional to the duration of activities. This was not a complete assessment of cost risk because it ignored other cost-type risks that are not related to schedule such as risks affecting the time dependent resources'

Construction Project Cost without Contingency or Padding	
Activity	($ millions)
Approval Process	$ 2.1
Environmental	$ 5.4
Design	$ 46.0
Procurement	$ 210.8
Install Equipment	$ 7.7
Construction	$ 335.8
Integration and Test	$ 16.5
Total Estimated Cost	$ 624.2

Table 1 — Example Project Cost by Activity

burn rate per day and the uncertainty in time-independent equipment or material cost.

The integrated cost-schedule risk analysis has several inputs, uses specialized Monte Carlo simulation tools, and produces several valuable outputs.

Inputs

The Cost Estimate

The cost estimate is a basic input to the risk analysis. Since the risk analysis calculates the probability of achieving the cost estimate and allows the organization to calculate the cost contingency reserve, the cost elements used as inputs need to be stated without contingency embedded in them. A good rule is to make the cost estimate, for each project element, the unbiased "most likely" estimate. Some estimators are uncomfortable about stripping the contingency amounts from the estimate, but the Monte Carlo simulation will re-estimate the contingency reserve that is appropriate for:

- the risks to the specific project's cost plan; and,
- the desired level of certainty of the project management and other stakeholders.

The values of cost that will be assigned to the activities in the schedule are based on the resources that will be used to accomplish and manage the work and the daily rate of those resources. The cost of a project component may involve several assigned resources, some of which are time-dependent and others are time-independent:

- Time dependent resources cost more the longer they are employed, e.g., construction, detailed engineering, heavy-lift barges and drilling rigs, equipment, project management team or procurement. These resources may cost more or less even if the activity duration is fixed since the burn rate per day may be variable.
- Time independent resources such as procured equipment and raw materials, even subcontracts (particularly before they are awarded) may cost more or less than the engineering estimate, but not because they take longer to produce and deliver.

In this article, the authors use a simple project as an example. It is a construction project estimated to cost $624 million over a 28-month period. The cost estimate is shown in table 1.

The CPM Schedule

The platform for the integrated cost-schedule risk analysis is a cost-loaded CPM schedule. To incorporate the schedule risk into the cost risk, the schedule has to be taken into account directly and transparently.

For an integrated cost-schedule risk analysis (and for schedule risk analysis) a summary schedule needs to be:

- integrated;
- include representation of all the work;
- has activities properly linked with logic; and,
- includes enough detail to highlight the main project milestones to be used.

Experience shows that schedules of 300 – 1,000 activities can be used in a risk analysis, even of projects as large as $10 billion.

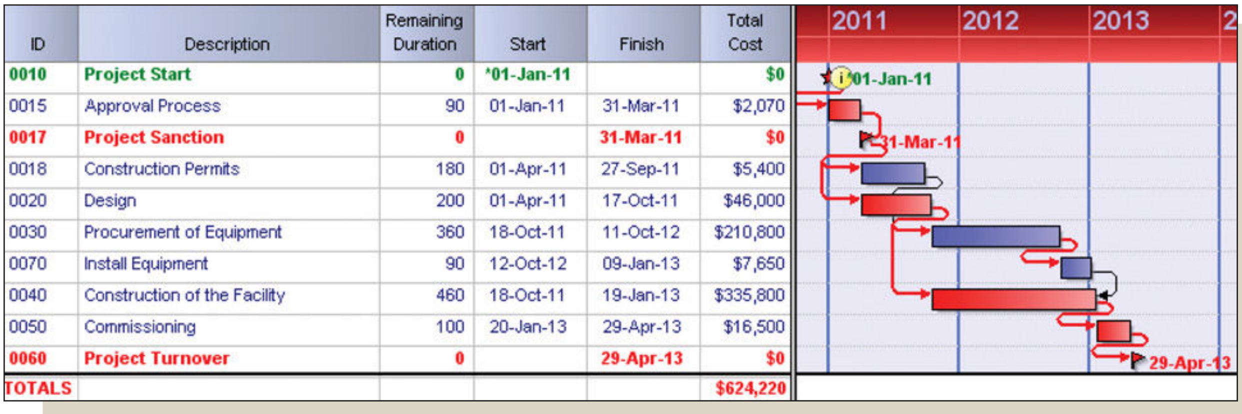
A detailed schedule may be used but it has several limitations:

- It is usually too difficult to identify and correct a detailed schedule with many activities and logical relationships for best practices.
- Applying resources to activities is more difficult for a detailed schedule than for a summary schedule, even if summary resources are used. And,
- Simulation of the detailed schedule with risks attached is often time consuming.

The first task in the risk analysis of cost and schedule is to debug the schedule. The schedule needs to follow CPM scheduling recommended practices because it needs to calculate the milestone dates and critical paths correctly during Monte Carlo simulation. It should be noted that the scheduling requirements for schedule risk analysis and for high quality CPM schedules are the same.

The scheduling principles that are particularly important to the success of a Monte Carlo simulation include:

- All work needed to complete the project must be represented in the schedule, because: (1) one does not know whether the critical path or risk critical path will be a priority, and (2) for integration of cost and schedule risk, one needs to be able to assign all the project cost to appropriate activities.
- The logic should not contain any open ends, called "danglers." This means that: (1) each activity, except the first activity, needs a predecessor to drive its start date, and (2) each activity, except the final



ID	Description	Remaining Duration	Start	Finish	Total Cost
0010	Project Start	0	*01-Jan-11		$0
0015	Approval Process	90	01-Jan-11	31-Mar-11	$2,070
0017	Project Sanction	0		31-Mar-11	$0
0018	Construction Permits	180	01-Apr-11	27-Sep-11	$5,400
0020	Design	200	01-Apr-11	17-Oct-11	$46,000
0030	Procurement of Equipment	360	18-Oct-11	11-Oct-12	$210,800
0070	Install Equipment	90	12-Oct-12	09-Jan-13	$7,650
0040	Construction of the Facility	460	18-Oct-11	19-Jan-13	$335,800
0050	Commissioning	100	20-Jan-13	29-Apr-13	$16,500
0060	Project Turnover	0		29-Apr-13	$0
TOTALS					$624,220

Figure 1 — Example Construction Project Schedule

delivery, needs a relationship from its finish date to a successor.

- The schedule should not rely on constraints to force activities to start or finish by certain dates. It should use logic for this purpose. Date constraints can turn a CPM network into a calendar.
- Lags and leads are appropriate only in limited circumstances and are generally to be avoided in project scheduling. And,
- The schedule used should be the statused current schedule.

These points are consistent with those found in **GAO Cost Estimating and Assessment Guide** [1].

It is good scheduling practice to review the total float values to make sure they are reasonable. Large float values may indicate incomplete logic; and perhaps, the need to introduce and logically link additional activities.

Simple Construction Case Study

A simple schedule example of a 28-month construction project is shown in figure 1. This figure and several others shown in this article are screen shots from Primavera Risk Analysis, formerly Pertmaster Risk Expert, now owned by Oracle.

Resources Loaded into the CPM Schedule

Loading resources into the CPM schedule for the purpose of integrated cost-schedule risk analysis can be accomplished using summary resources. Summary resources are not sufficiently detailed to perform resource leveling. Their purpose is to get the entire budget into the project schedule. Simple categories of resources that can be given budgeted values and placed on the activities they work on are needed. Resources used on the simple construction project are shown in table 2.

In addition, the resources need to be tagged as "labor-type"—time-dependent resources; or "material-type"—time-independent resources, as mentioned above. An alternative method of applying resources to the schedule, when the cost estimate is not specified down to the detail of the schedule activities, is to apply resources to hammocks that span the activities that get the resources.

Resources

Resources are applied to the schedule activities, Sometimes, in doing this, the cost estimate and schedule have evolved largely independently of one another and the cost estimates are not consistent with the activity durations. It is important that if the estimate and schedule are initially developed independently of one another, that they are reconciled prior to holding the risk assessment, or else the implied "daily rates" of cost will be wrong.

The costs that result from placing the resources on the example project schedule are shown in table 3.

ID	Description	Type	Default Loading
COMM	Commissioning	Labor	Normal
CONS	Construction	Labor	Normal
ENG	Engineers	Labor	Normal
ENV	Environmental	Labor	Normal
MGT	Management	Labor	Normal
PMT	Project Management Team	Labor	Normal
PROC	Procurement	Materials	Spread

Table 2 — Resources for Example Construction Project

THE RISK DRIVER METHOD

Risk Data Inputs for the Risk Driver Method

Applying first principles requires that the risk to the project cost and schedule is clearly and directly driven by identified and quantified risks. In this approach, the risks from the risk register drive the simulation.

The risk driver method differs from older, more traditional approaches—wherein the activity durations and costs are given a 3-point estimate which results from the influence of potentially

Cost Estimate by Resource and Activity ($ thousands)								
Activity	PMT	MGT	ENV	ENG	PROC	CONS	COMM	Total
Approval	720	1350						2,070
Environmental	900		4500					5,400
Design	6,000			40,000				46,000
Procurement	10,800				200,000			210,800
Install Equipment	2,250					5,400		7,650
Construction	13,800					322,000		335,800
Commissioning	1,500						15,000	16,500
Total	35,970	1,350	4,500	40,000	200,000	327,400	15,000	624,220

Table 3 — Cost Example Construction Project Showing Resources

several risks, which cannot be individually distinguished and kept track of. Also, since some risks will affect several activities, one cannot capture the entire influence of a risk using traditional 3-point estimates of impact on specific activities.

Using the risk driver method, the risks that are chosen for the analysis are generally those that are assessed to be "high" and perhaps "moderate" risks from the risk register. Risks are usually strategic risks rather than detailed, technical risks.

While the risk data are collected in interviews with project SMEs, new risks emerge and are analyzed. There may be perhaps 20-40 risks, even in the analysis of very large and complex projects. Risks to project schedule and cost include:

- risk events that may or may not happen; and,
- uncertainties that will happen but with uncertain impact.

Once the risks are identified from the risk register, certain risks data are collected:

- Probability of occurring with some measurable impact on activity durations and/or costs. In any iteration during the Monte Carlo simulation, a risk will occur or not depending on its probability.
- The risk also has an impact on project activities if it does occur. This impact is specified as a range of possible impacts, stated in multiples of the activity's estimated duration and cost. If the risk does occur, the durations and costs of the activities in the schedule that the risk is assigned to will be multiplied by the multiplicative impact factor that is chosen from the impact range for that iteration.
- The risks are then assigned to the activities and resources they affect.

Collection of risk data relies on the processes of the risk identification and risk prioritization. It is important during

			Duration Impact Ranges (%)			Cost Impact Ranges (%)		
Risk ID	Risk Description	Prob	Min	ML	Max	Min	ML	Max
1	S/C - Design Complexity may Challenge Engineers	40	90	110	135	100	105	110
2	S -Site Conditions / Site Access may Slow Logistics	50	100	110	125			
3	S/C-Equipment Suppliers may be busy	60	100	105	120	100	110	120
4	S - Capable Management may not be Assigned	40	90	105	115			
5	S -Environmental Agency May be Slow	50	95	110	135			
6	S - Activity Duration Estimates is Inaccurate	100	90	105	115			
7	C - Cost Estimate is Inaccurate	100				95	105	115
8	S/C Key Engineering Personnel may be Unavailable	65	95	105	120	90	100	110

Table 4 — Example Risks and Their Parameters For The Case Stude

risk data collection to be alert to possible biases that crop up during workshops. Some people want to influence the results, while others genuinely do not understand the concepts or have some cognitive bias that has to be overcome. One approach is to conduct risk interviews with individuals, or small groups, for which there is a promise of confidentiality to the participants. This is so they can talk honestly and openly without fear that management will be displeased with them.

The degree of correlation between the activity durations has long been viewed as being important for understanding and estimating correctly the project cost risk analysis. Correlation arises if one risk affects two (or more) activities' durations, or if a risk affects the cost of two time-independent resources. If a risk occurs, the degree to which their durations are longer and shorter together is called correlation. As shown below, the risk driver method causes correlation between activity durations, so one no longer has to estimate (guess) at the correlation coefficient between each pair of activities.

Probabilistic branching, or existence risk, requires another type of risk data—the probability that an activity and its cost will exist on this project. Some risks may cause activities to occur only if the

	Activities						
Risks	Approval Process	Environ-mental	Design	Procure-ment	Install Equipment	Construction	Commissioning
S/C - Design Complexity may Challenge Engineers	X		X				
S -Site Conditions / Site Access may Slow Logistics						X	X
S/C- Equipment Suppliers may be busy				X			X
S - Capable Management may not be Assigned	X					X	X
S - Environmental Agency May be Slow		X					
S - Activity Duration Estimates is Inaccurate	X		X	X	X	X	X
C - Cost Estimate is Inaccurate	X		X	X	X	X	X
S/C Key Engineering Personnel may be Unavailable	X	X	X	X	X	X	X

Table 5 — Assigning Risks to Activities

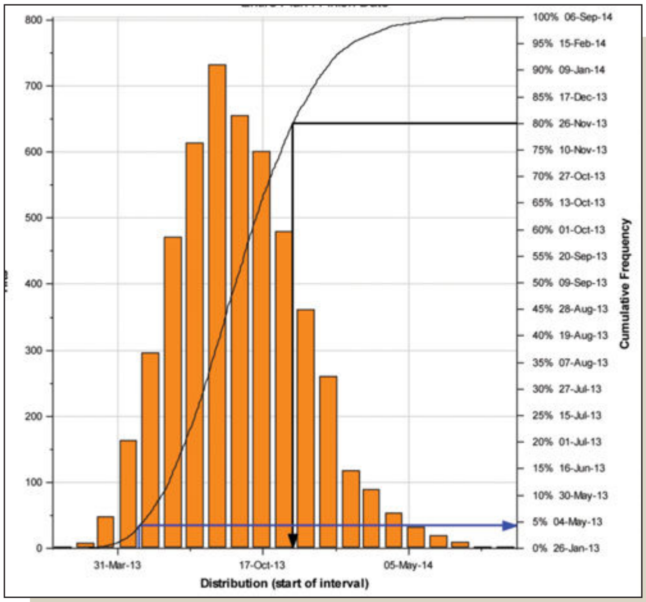


Figure 2 — Histogram with Cumulative Distribution (S-Curve) for the Project Completion Date

risk occurs. Some risk events such as failure of a test or a commissioning activity, if they occur, may require new activities such as finding the root cause of the failure, determining the recovery plan, executing the recovery plan, and retesting the article. These activities will all take time and increase project cost. They can be inserted in the schedule as probabilistic branches, or existence activities, with time and cost implications if they occur.

Simulation Using the Risk Drivers Method

In the simple example used in this article, the risks' impacts are specified as ranges of multiplicative factors that are then applied to the duration or cost of the activities to which the risk is assigned.

The risks operate on the cost and schedule as follows:

- A risk has a probability of occurring on the project. If that probability is 100%, then the risk occurs in every iteration. If the probability is less than 100%, it will occur in that percentage of iterations.
- The risks' impacts are specified by 3-point estimates of multiplicative factors, so a schedule risk will multiply the scheduled duration of the activity to which it is assigned. The 3-point estimate, for instance, (low 90%, most likely 105% and high 120%), is converted to a triangular distribution. For any iteration, the software selects an impact multiplicative factor at random from the distribution. If the risk occurs during that iteration, the multiplicative factor selected multiplies the duration of all the activities to which the risk is assigned.
- The cost risk factor is applied differently depending on whether the resource is labor-type or equipment-type.
    - For a **labor-type resource**, the cost risk factor varies the daily burn rate, representing more or fewer resources applied, higher or lower cost of those resources per day. For these resources, their total cost is also affected by the uncertainty in the duration, but they may cost more or less even if their durations are as scheduled.
    - For **equipment-type resources**, the cost risk factor varies the total cost. For these resources, the cost may be uncertain but it is not affected by time.

Simulation Tools

Monte Carlo simulation is the most commonly applied method for conducting quantitative risk analysis. A Monte Carlo simulation calculates the possible project cost and schedule values that may result from individual risks and translates them into project-level cost and schedule histograms or distributions from which statistical statements can be made.

Since one does not know whether any risk will occur on any specific project

Summary Schedule Risk Analysis Results Example Construction Project						
Scenario		Schedule Probabilistic Results				
Deterministic	29-Apr-13	P-5	P-50	P-80	P-95	Spread
Prob. Deterministic	4%	4-May-13	9-Sep-13	26-Nov-13	15-Feb-14	P-5 To P-95
All Cost and Schedule Risks		Months				
Difference from Deterministic		0.2	4.4	6.9	9.6	9.4

Table 6 — Summary Schedule Risk Analysis Results for the Example Construction Project

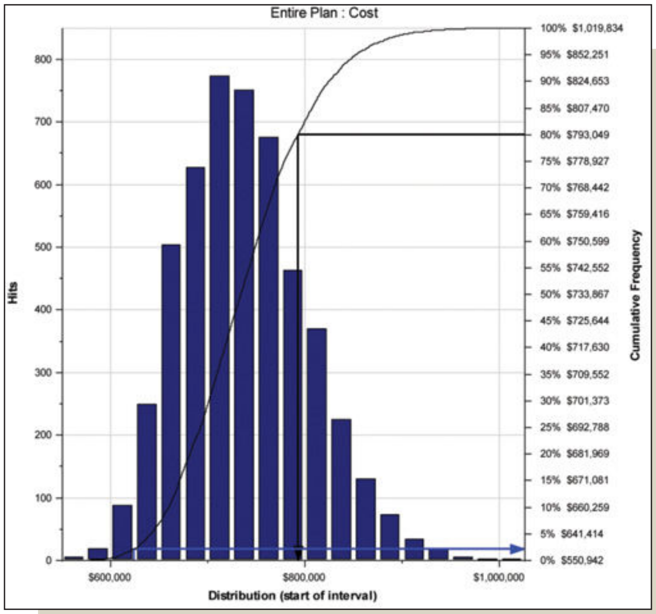


Figure 3 — Histogram with Cumulative Distribution (S-Curve) for the Project Cost

or what its impact will be, one cannot tell when a project will finish or how much it will cost. One can only tell probabilistically when the project might finish and how much it might cost.

Suppose the simulation contains 3,000 iterations—separate runs using randomly-selected risk data—and creates 3,000 pseudo-projects. Each of the 3,000 projects could be the sample project in this article, since it is based on a different combination of risks applied to this project schedule and cost. These different combinations of input data generally compute different completion dates and project costs. The Monte Carlo simulation provides probability distributions of cost and schedule from which one can make probabilistic statements about this project.

Risk Data Used for the Construction Case Study

The following is a sample case study, but the risks are similar to those found on real projects.

Suppose there is a project with the activities shown in figure 1, and resources/costs as shown in table 1, and assigned to the activities as shown in table 3. Also, suppose one has identified risks through a workshop or interviews and have elicited the probability and time/cost impacts as shown in table 4.

After the risks are listed and their parameters quantified, they need to be assigned to the activities and their resources. For this case study the risks are assigned according to table 5.

Results From the Construction Case Study Simulation

The schedule risk results from a Monte Carlo simulation are shown in the histogram for the case study in figure 2. It shows that the deterministic date of 29 April 2013, is about 4% likely to be achieved following the current plan and without further risk mitigation actions.

Next, suppose that the project stakeholders have agreed that their acceptable level of confidence is at the 80th percentile. At that point, it is 80% likely that the current project plan with all of its risks will finish on that date or earlier (and, if it is applied to cost, with

Summary Cost Risk Analysis Results Example Construction Project ($ millions)						
Scenario		Cost Probabilistic Results				Spread
Deterministic	624	P-5	P-50	P-80	P-95	P95-P5
Prob. of Deterministic	2%	641	734	793	852	
Difference from Deterministic $		17	110	169	228	211
Difference from Deterministic %		3%	18%	27%	37%	

Table 7 — Summary Cost Risk Analysis Results for the Example Construction Project

Decompose the Cost Contingency at the P-80		
	P-80	Marginal Impact
	($ millions)	
Contingency-Free Cost Estimate	624	
All Risks	793	
Cost Risks Only	702	78

Table 8 — Cost, Schedule and Interaction Effects

that cost or less). At the P-80, the project finishes on 26 November 2013, or earlier, and needs about a 7-month contingency reserve of time. These results are shown in figure 2 and in table 6.

The cost risk results, including the impact on cost of schedule risk, indicate the need for a contingency reserve of cost of about $169 million, or 27% at the 80th percentile (P-80). At that level there is an 80 percent probability that the project will cost $793 million or less, given the risks and following the current plan. These results are shown in figure 3 and table 7.

One can find out whether cost-type risks or schedule-type risks are more important in determining the cost contingency to, say the P-80 point. The source of the cost contingency can be discovered by eliminating all schedule risks, so as to compute the marginal impact of cost risks, then repeating the process by eliminating the cost risks and computing the impact of schedule risks on contingency. The results are shown in table 8.

Table 8 shows that if only cost risks were present (the schedule is static) the cost contingency at the P-80 could be $78 million, whereas if only schedule risks were included (no cost risk on burn rate or on procurement/materials), the contingency needed at the P-80 is $103. These results depend on the case study assumptions, but in many examples of integrated cost and schedule risk conducted on projects, the majority of the risk to cost arises from uncertainty in the schedule as it does in the example in this article.

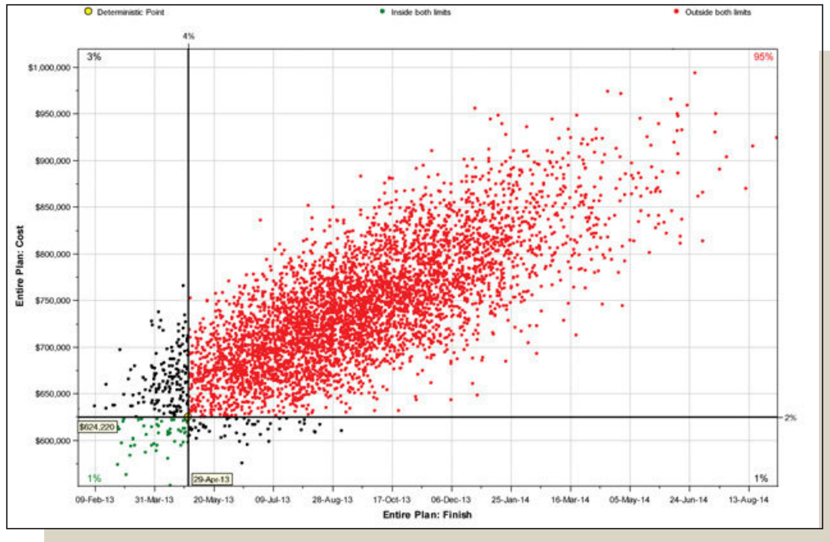


Figure 4 — Cost and Time Results From the Simulation

Correlation Between Cost and Schedule

The time-cost scatter diagram, shown in figure 4, is diffuse because there are some time-independent cost risks that affect the burn rate of labor-type resources and total cost of procured items. The cross-hairs shown on the diagram cross at the deterministic point of 29 April 2013 and $624.2 million. The sparse collection of points in the lower-left quadrant indicate that there is only a 1% chance that this project will satisfy both cost and schedule targets without contingency reserve. There is also a 95% chance that this project, following this plan, will overrun both cost and time objectives.

There is clearly a positive slope running through the cloud or "football (US version) chart," showing the strong impact on cost of schedule risks. The correlation between time and cost is 77% in this case study, which is somewhat higher than is common in these analyses.

Probabilistic Branches or Project-Busting Risks

Some risks will add activities to the project schedule if they occur, and hence will add time and cost. Most often a project plan assumes that the project goes well and that there are no major problems. It is also common that something goes wrong leading to a mandatory change in plans as the project tries to recover from a discontinuous event. An example of this problem might be the failure of the project at commissioning or final testing. These activities might be:

- Determine the root cause of the failure;
- Decide what to do;
- Implement the action; and,

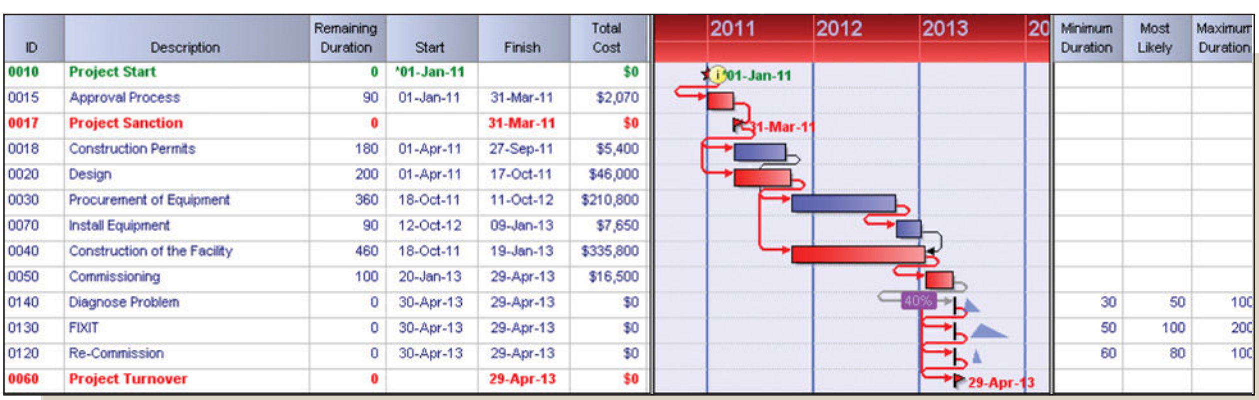


Figure 5 — Activities Added to Provide for a Risk That Commissioning May Not Complete Successfully

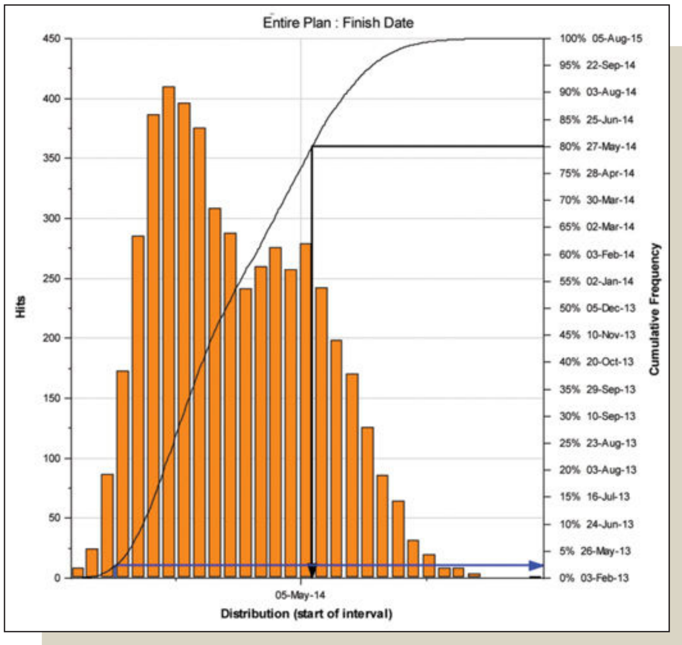


Figure 6 — Schedule Impact of Probabilistic Branch on Commissioning

- Re-test and, hopefully, pass the test this time.

One common characteristic of these activities is that they are almost never found in the initial project schedule, which assumes success. However, in risk analysis, the possibility of test failure or some other discontinuous uncertain event, must be modeled using existence risks or probabilistic branching.

Suppose that the commissioning activity might uncover a problem that takes time to fix. Simple changes can be made in the project schedule to accommodate this potentially project-busting occurrence. One cannot use the risk drivers that are assigned to existing activities, since when one introduces them they are given a duration of zero (0) days. Their uncertainty is represented by traditional 3-point estimates, but their risk source is known. An implementation of probabilistic branching is shown in figure 5. The probability that commissioning will not complete successfully the first time is estimated as 40%.

The schedule results for adding a probabilistic branch are shown in figure 6. Notice that the schedule is slightly bi-modal, with 60% of the results in the left-hand part of the distribution and 40% in the right-hand part. There is a bit of a "shoulder" in the cumulative distribution at 40%, that follows the specification that the commissioning will fail 40% of the time.

The cost of the project goes up at the P-80, since resources are placed on the activities in the probabilistic branch. The impact on cost and schedule of a 40% probable problem during commissioning, (with the parameters shown here), are shown in table 9.

Prioritized Risks to Schedule and Cost

If the risk results for the overall schedule and cost are not "acceptable" to the customer, the analyst can prioritize the risks for the project manager who will want to mitigate the highest-priority risks.

- For schedule risk, one needs to identify the most important risk by taking each risk out entirely (make the probability = 0%) one-at-a-time and re-run the simulation to determine the P-80 date, allowing one to identify the risk that has the greatest marginal impact on the P-80 date. Then, keeping the most important risk out, one explores the remaining risks to see which of those is next-most-important, and so forth. And,
- For cost risk, this is done by taking each risk out of the project one at a time, computing the impact to the P-80 cost compared to the all-in results, and finding the risk that has the largest impact on the P-80 cost. It is logical to identify the schedule risks that have cost risk implications as described above, but the list of the risks in order of priority may differ for time and for cost.

Effect on Cost and Schedule Risk of Possible Commissioning Failure			
	No Commissioning Risk	Commissioning Risk @ 40%	Difference
Schedule			Days
P-80 Date	26-Nov-13	27-May-14	182
Probability of 29 April 2013	4%	2%	-2%
Cost	$ millions		
P-80 Cost	$ 793.0	$ 829.5	36.5
Probability of $624,220	2%	1%	-1%

Table 9 — Schedule and Cost Impact of a 40% Probable Commissioning Risk

Priority Schedule Risks			
Risk ID	Risks	P-80 Date	Contribution to the P-80 Contingency
	ALL RISKS INCLUDED	27-May-14	(Days)
Risks Removed			
9	S/C - May have Problems during Commissioning	13-Nov-13	195
8	S/C Key Engineering Personnel may be Unavailable	4-Oct-13	40
6	S - Activity Duration Estimates is Inaccurate	18-Aug-13	47
2	S -Site Conditions / Site Access may Slow Logistics	6-Jul-13	43
1	S/C - Design Complexity may Challenge Engineers	19-Jun-13	17
3	S/C-Equipment Suppliers may be busy	30-May-13	20
4	S - Capable Management may not be Assigned	6-May-13	24
5	S -Environmental Agency May be Slow	29-Apr-13	7

Table 10 — Highest Priority Risks to Project Schedule at the P-80 Level of Confidence

Tables 10 and 11 show which risks are the most important for schedule and for cost.

Risk Mitigation Using Prioritized Risks

Using the prioritized risks in table 8, one can recommend risk mitigation. The first thing to recognize is the inaccuracy of the estimates, which is viewed as moderate at risk impact multipliers of 95%, 105% and 115%. However, this risk is 100 % likely to occur, since estimating error is with one until project financial completion, and it is assigned to each activity in the project, hence its importance. The next item to be concerned about is the probability of problems during commissioning, which is also the highest schedule risk. The next largest item would be the unavailability of key engineering staff. Down the list at position five is the inaccuracy of the schedule.

In fact, in the simple example the authors created for this article, only the top risk to project cost is a pure cost risk. The other important risks are mostly schedule risks (some with cost risk components, see table 4) that increase cost if their activities are longer than assumed in the schedule.

These schedule risks may be missed or underestimated if the cost risk analysis does not explicitly handle the relationship of time and cost risk, as is shown in the approach described in this article. It is common to find that schedule risks are important in driving cost risk. It reinforces the benefits of integration of cost and schedule.

Conclusion

Integrating cost and schedule risk into one analysis, based on the project schedule loaded with costed resources from the cost estimate provides both:

- more accurate cost estimates than if the schedule risk were ignored or incorporated only partially; and,
- illustrates the importance of schedule risk to cost risk when the durations of activities using labor-type (time-dependent) resources are risky.

Many activities such as detailed engineering, construction or software development are mainly conducted by people who need to be paid even if their work takes longer than scheduled. Level-of-effort resources, such as the project management team or QA/QC, are extreme examples of time-dependent resources, since if the project duration exceeds its planned duration the cost of these resources will increase over their budgeted amount.

The integrated cost-schedule risk analysis is based on:

- A high quality CPM schedule.
- A contingency-free estimate of project costs that is loaded on the activities of the schedule using resources distinguishing them by their time-dependent and time-independent nature.
- Good-quality risk data that is usually collected in risk interviews of the project team, management and others knowledgeable in the risk of the project. The risks from the risk register are used as the basis of the risk data in the risk driver method. The Risk Driver Method is based in the fundamental principle that identifiable risks drive overall cost and schedule risk and that one can model this process. And,
- A Monte Carlo simulation software program that can simulate schedule

Priority Cost Risks			
Risk ID	Risks	P-80 Cost	Contribution to the P-80 Contingency
	ALL RISKS INCLUDED	829.5	
Risks Removed			
7	C - Cost Estimate is Inaccurate	788.3	41.2
9	S/C - May have Problems during Commissioning	750.4	37.9
8	S/C Key Engineering Personnel may be Unavailable	719.1	31.3
2	S -Site Conditions / Site Access may Slow Logistics	687.7	31.4
6	S - Activity Duration Estimates is Inaccurate	664.6	23.1
3	S/C-Equipment Suppliers may be busy	641.7	22.9
4	S - Capable Management may not be Assigned	632.6	9.1
1	S/C - Design Complexity may Challenge Engineers	625	7.6
5	S -Environmental Agency May be Slow	624.2	0.8

Table 11 — Highest Priority Risks to Project Cost at the P-80 Level of Confidence

risk, burn-rate risk and time-independent resource risk.

The results include the standard histograms and cumulative distributions of possible cost and time results for the project. However, by simulating both cost and time simultaneously, one can collect the cost-time pairs of results and hence show the scatter diagram ("football chart") that indicates the joint probability of finishing on time and on budget. Also, one can derive the probabilistic cash flow for comparison with the time-phased project budget.

The risks to schedule completion and to cost can be prioritized, say at the P-80 level of confidence, to help focus the risk mitigation efforts. If the cost and schedule estimates including contingency reserves are not acceptable to the project stakeholders, the project team should conduct risk mitigation workshops and studies, deciding which risk mitigation actions to take, and re-run the Monte Carlo simulation to determine the possible improvements to the project's objectives. ◆

REFERENCE

1. **GAO Cost Estimating and Assessment Guide**, US Government Accountability Office, March 2009 (GAO-09-3SP), pgs. 218-224.

RECOMMENDED READING

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2 Hulett, D.T., **Practical Schedule Risk Analysis**, Gower Publishing Limited, Farnham Surrey England. (2009): pg. 218.

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